


Can Renewable Energy Slow Global Warming?

Presented at

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Plenary Session E: Technology Solutions: Global Advances in Renewable Energy and Efficiency

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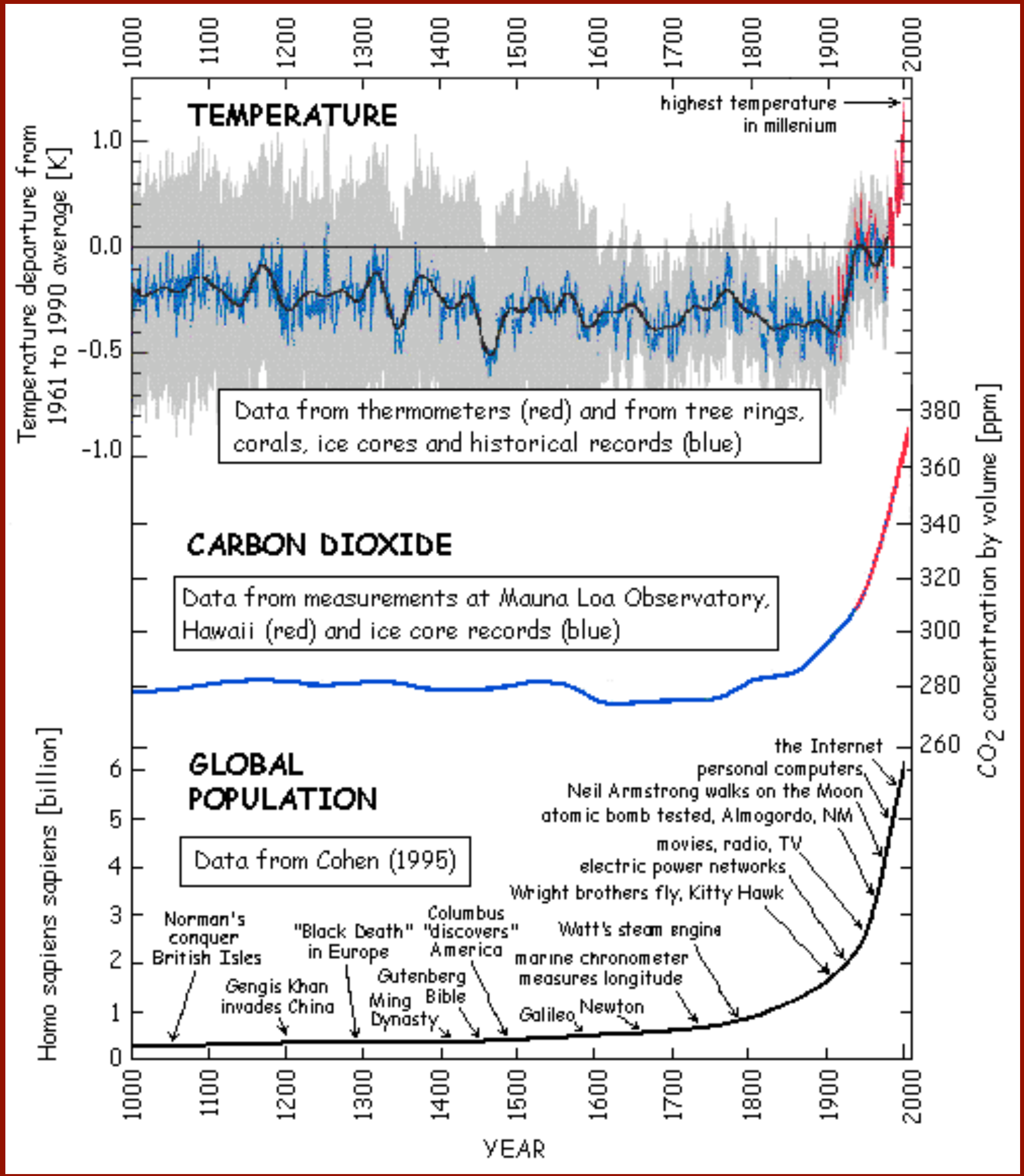
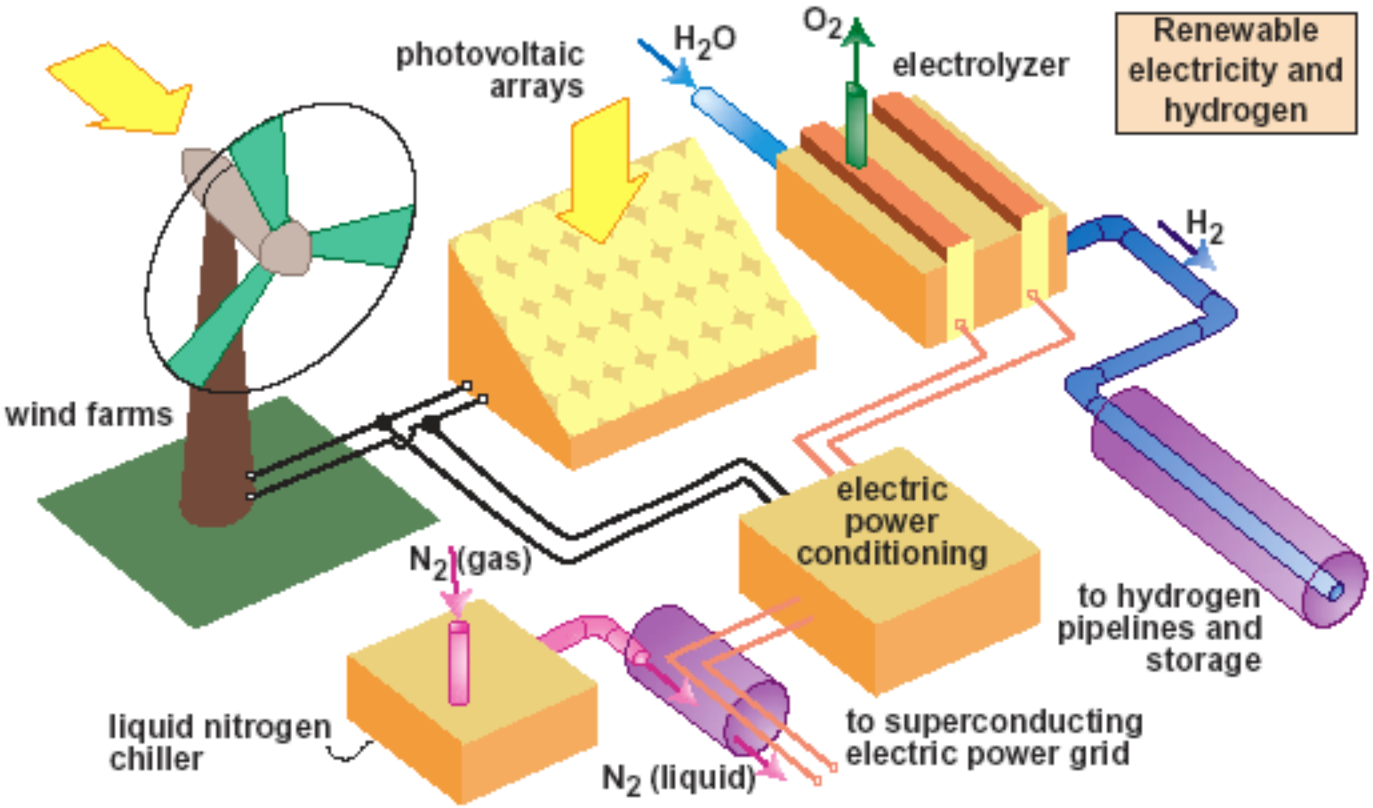
Global warming over the past millennium

Very rapidly we have entered uncharted territory -- what some call the *anthropocene* climate regime. Over the 20th century, human population quadrupled and energy consumption increased sixteenfold. Near the end of the last century, we crossed a critical threshold, and global warming from the fossil fuel greenhouse became a major, and increasingly dominant, factor in climate change. Global mean surface temperature is higher today than it's been for at least a millennium.



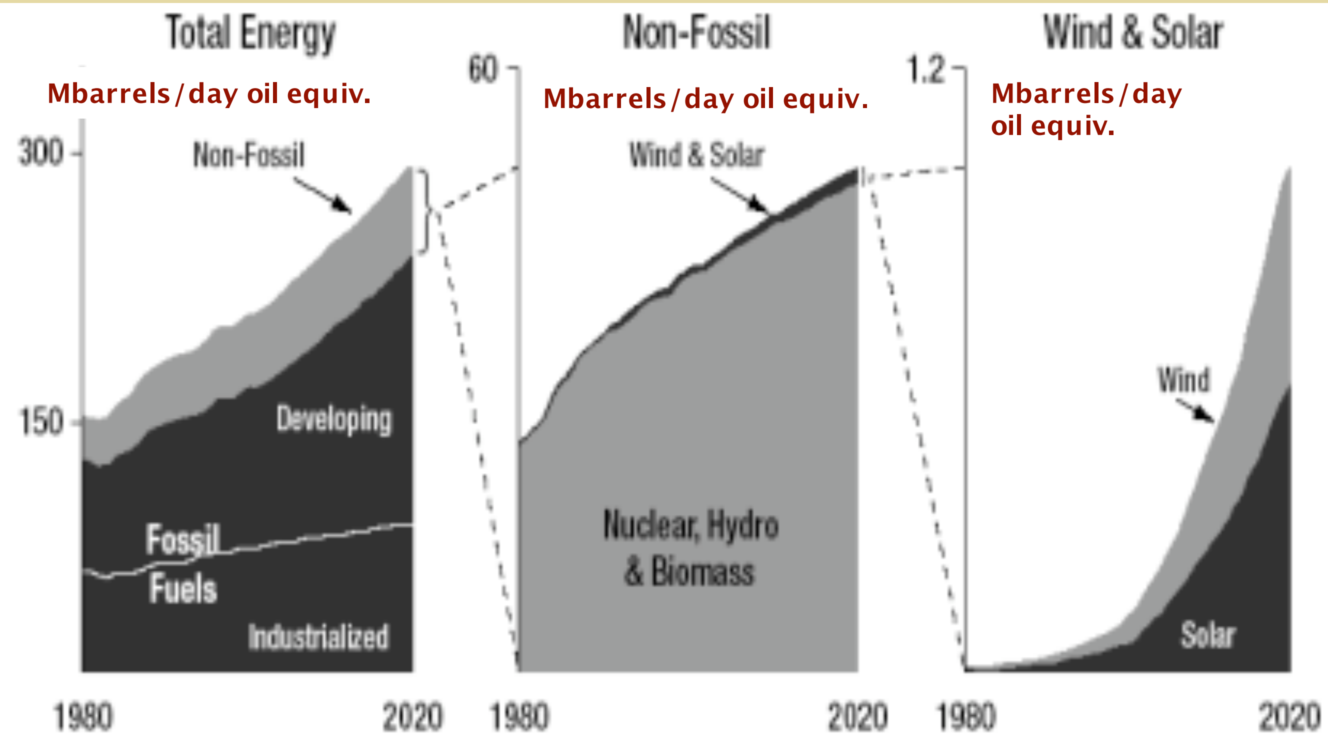


Mass-produced widely distributed PV arrays and wind turbines may eventually generate 10–30 TW emission-free

POLICY IMPLICATION FOR RENEWABLE ENERGY:

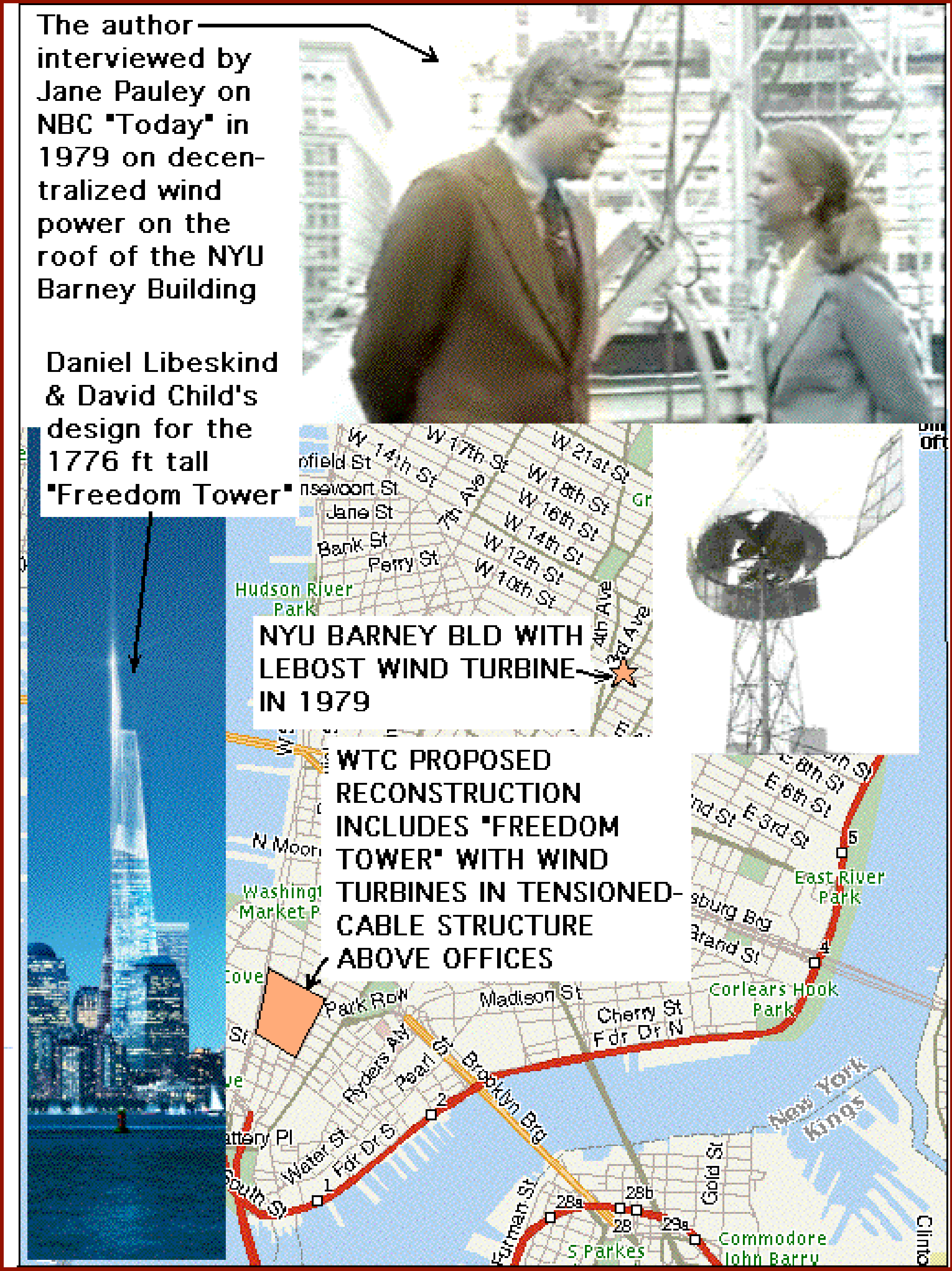
Some industry critics claim we will never power civilization with renewable energy. Fact: Wind & solar are fastest-growing primary power sources, but are unlikely to grow from present ~ 1% of supply to 10% by 2025 and >30% by 2050 without major incentives, R & D and demonstration of enabling technologies. There are no known show-stoppers

Energy Demand 1980-2020 (BAU)

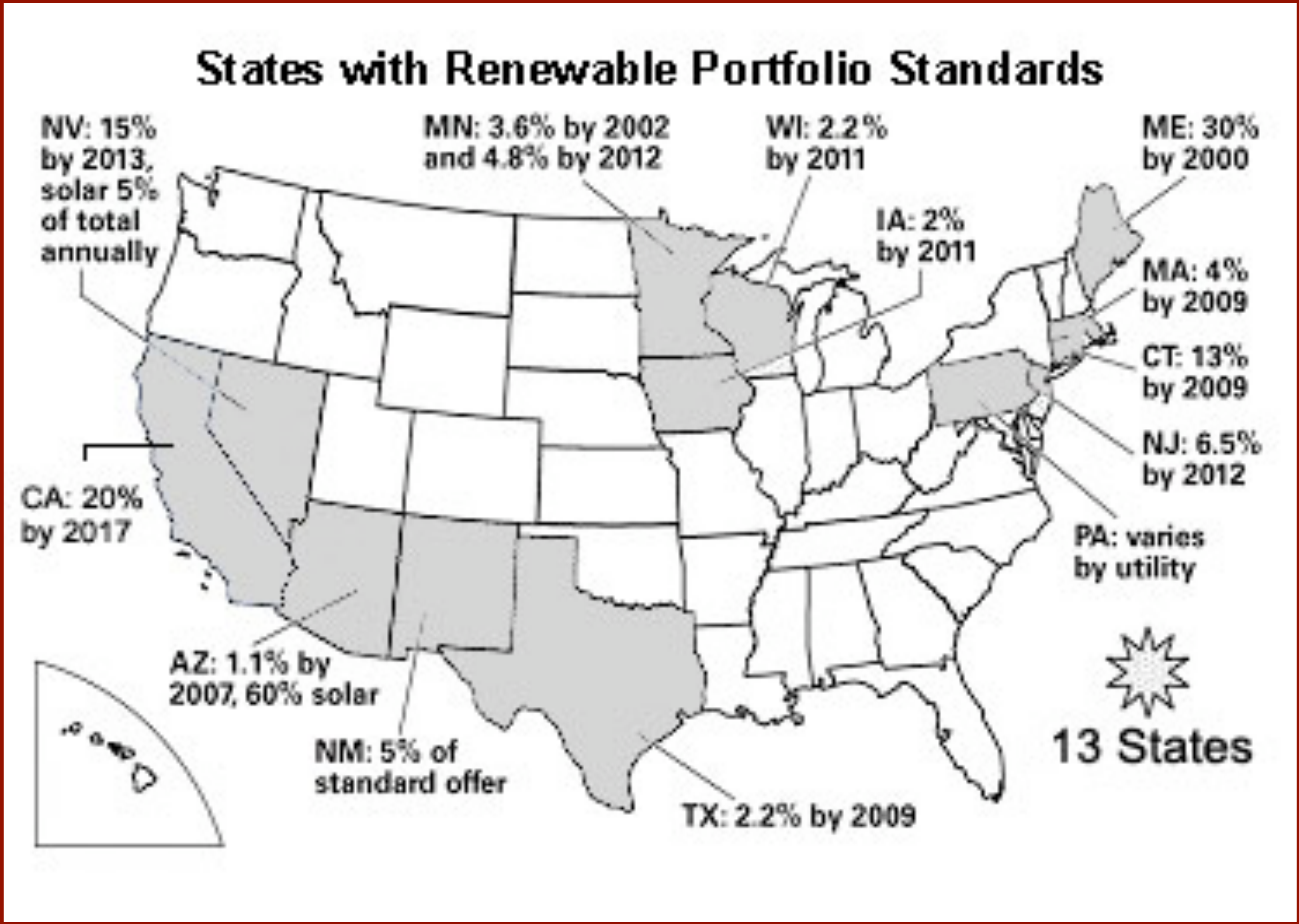


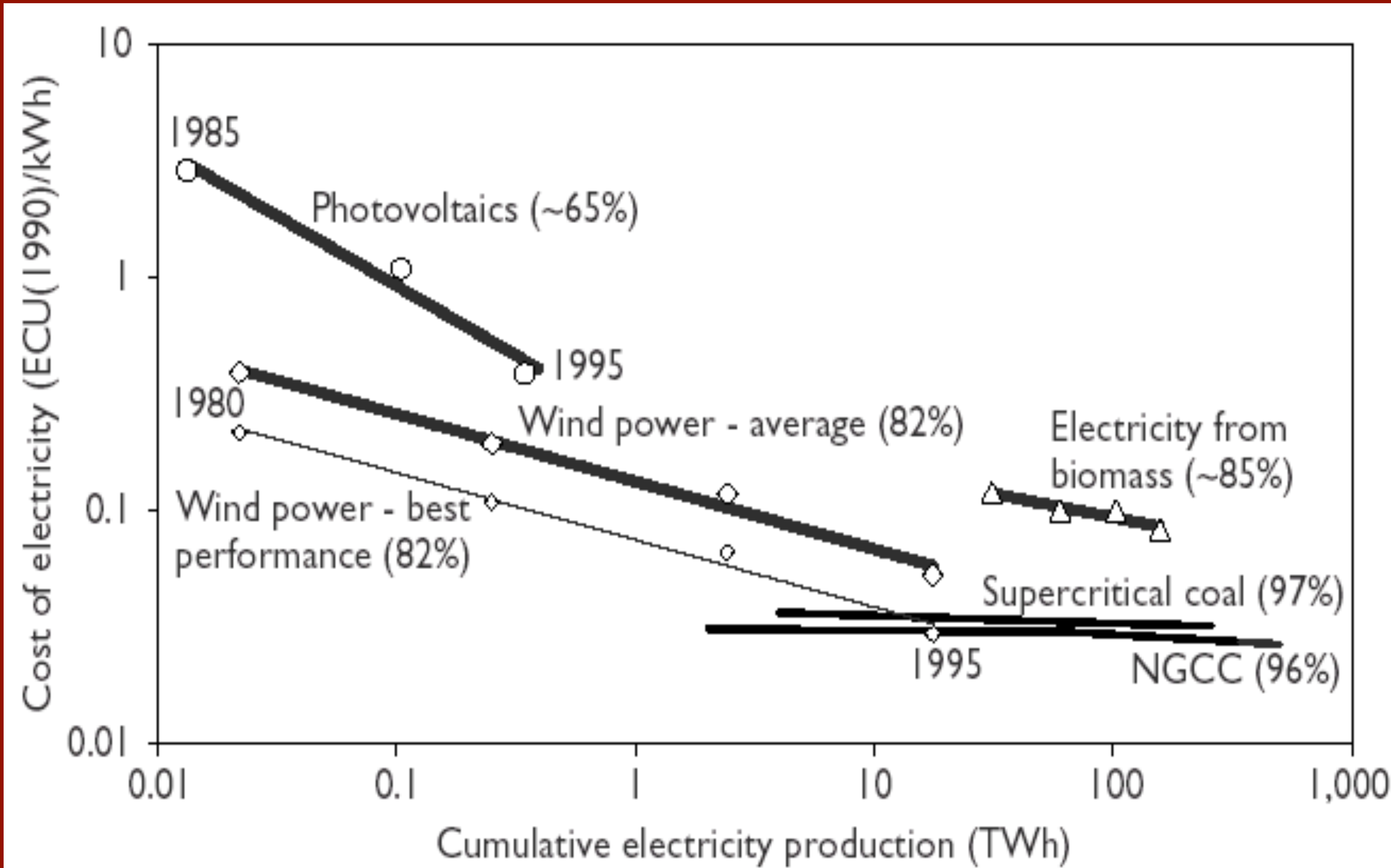
déjà vu: The double-finned beast on a microwave tower in the middle right of the collage at left is the Lebost Wind Turbine (LWT). The top is an image from an interview Jane Pauley of the NBC Today show did with me live from the Barney Building roof in the summer of '79 shortly after the LWT went up. The winning architectural design for the WTC reconstruction, the Freedom Tower by Daniel Liebeskin and David Child, is projected to contain wind turbines inside its open cable-tensioned upper structure, sufficient to generate 20% of the building's electricity -- the first wind turbine in lower Manhattan since we built the NYU LWT during the "Energy Crisis" of the 1970's.

We don't have 25 years to wait for the next ones.



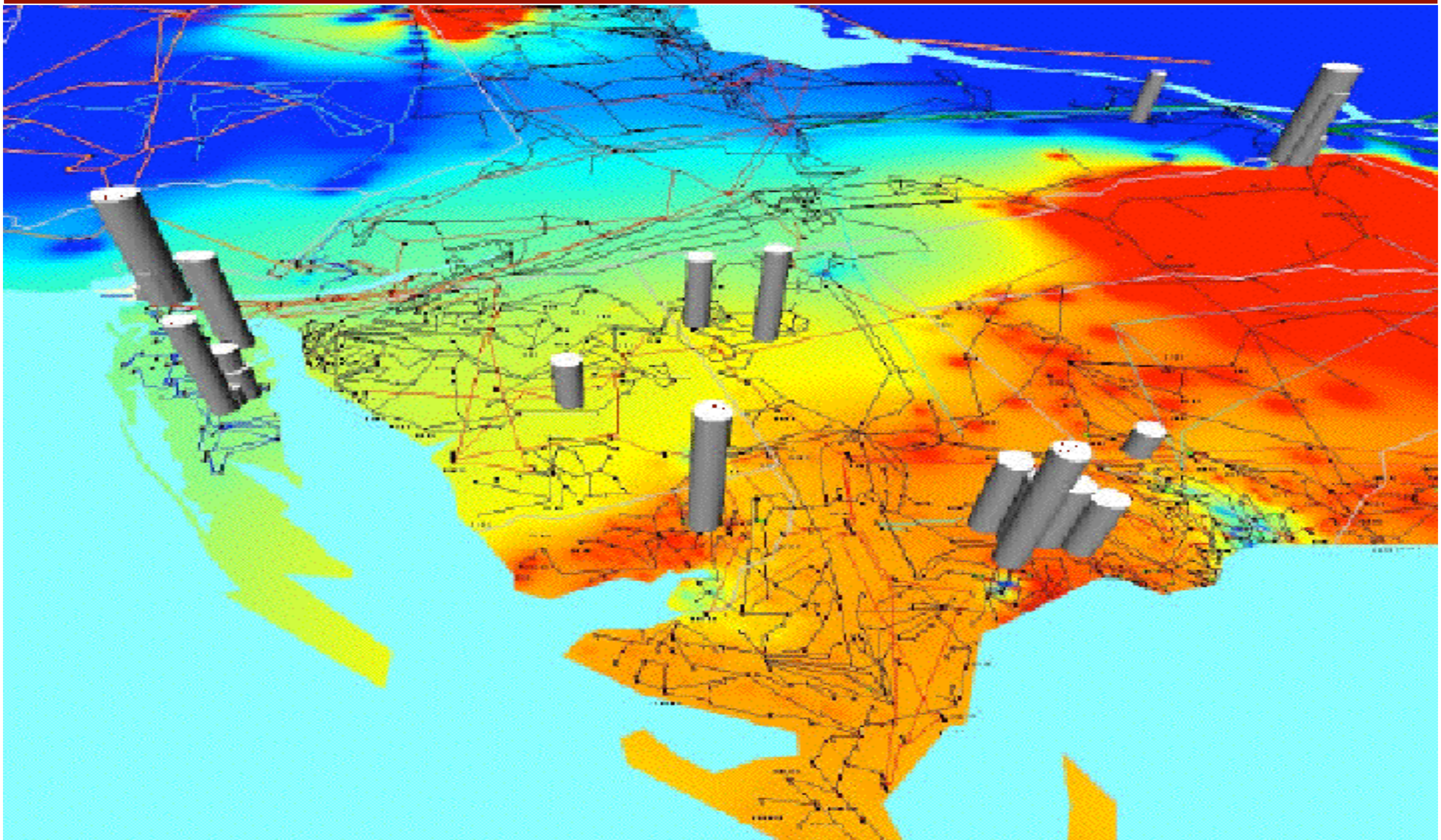
DoE/EIA Studies Put a 20% Federal RPS by 2020 at, or below, BAU Costs (D. Kammen)





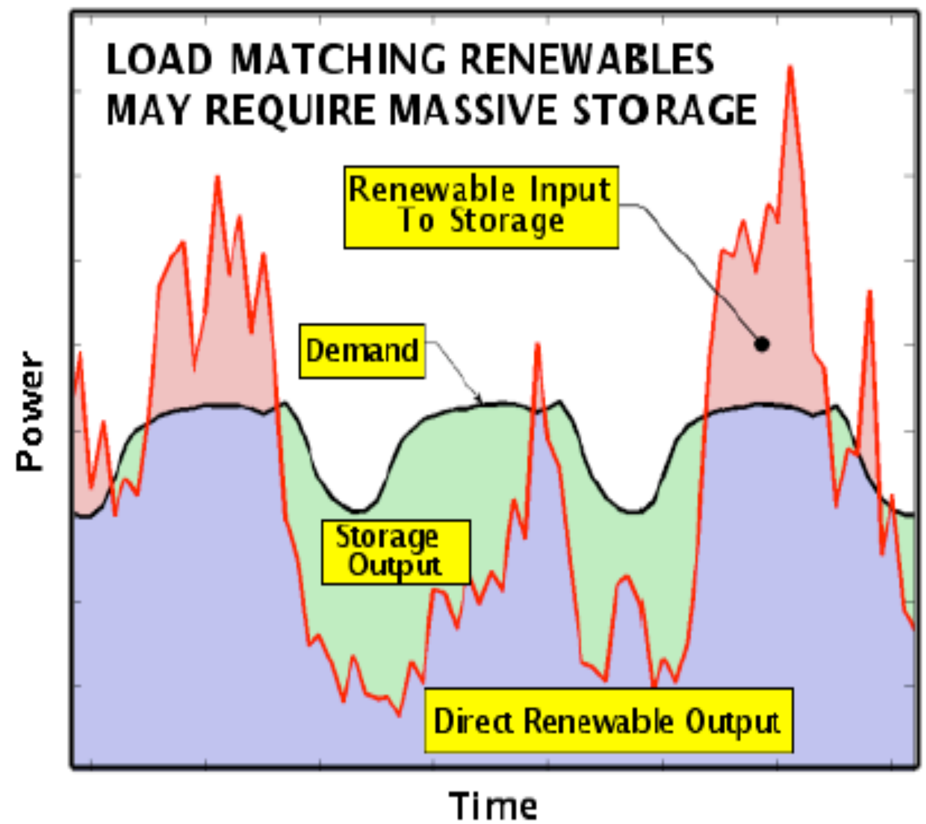
"Learning by Doing" cost reductions versus installed capacity for various electricity generating technologies (IEA, 2000)

Smart Grid Recognizes Regional Problems and Coordinates Remediation (R. Anderson)

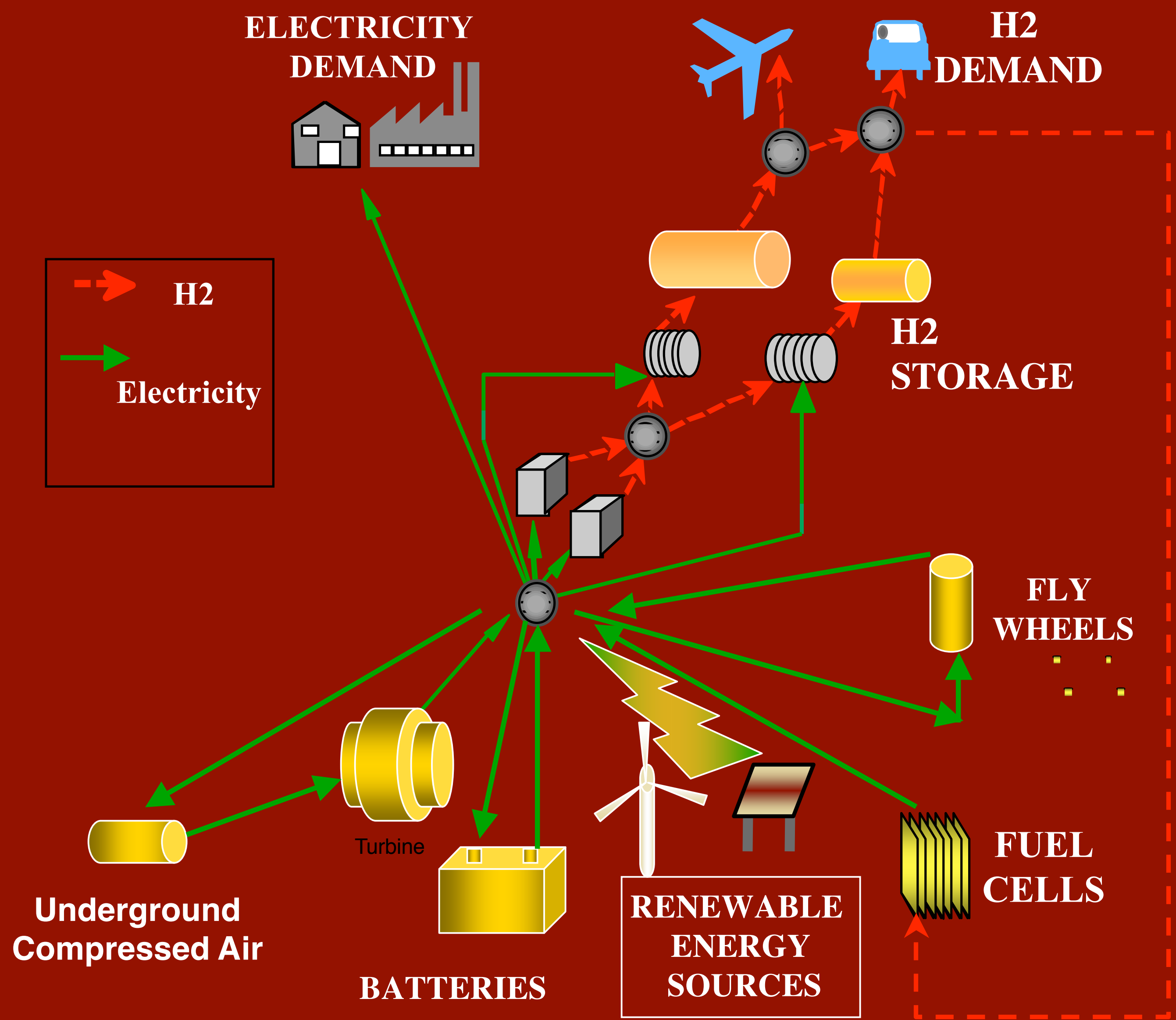


But entire Electric Grid must be Innervated for it to work

"Smart" and low-loss electrical grids. Electrical networks in the US and Europe are going to be reconstructed or added to in any event in the wake of recent power outages. We should take this opportunity to see how they can be made user-friendly to renewable power sources, which tend to be intermittent, distributed and often low in power. "Net metering" from the grid is acceptable so long as renewable sources are < 5-10% of the power, after which the grid must be redesigned to accommodate them. This needs to be studied *now*, to prevent foreclosing a major role for renewable electricity in the future. Reducing the electrical resistivity of such grids with high-temperature superconductors or carbon nanotubes is one element of this, computerized load management another. Energy storage is important enough to have a program of its own. Energy could be transported as electrical energy over wire, rather than by transport of mass (coal, oil, gas). Vast electrical power grid on a continental scale interconnecting ~ 200 million asynchronous "local" storage and generation sites would be explored.



Energy Storage Options



Flywheels
(high power)

Batteries
(convenience)

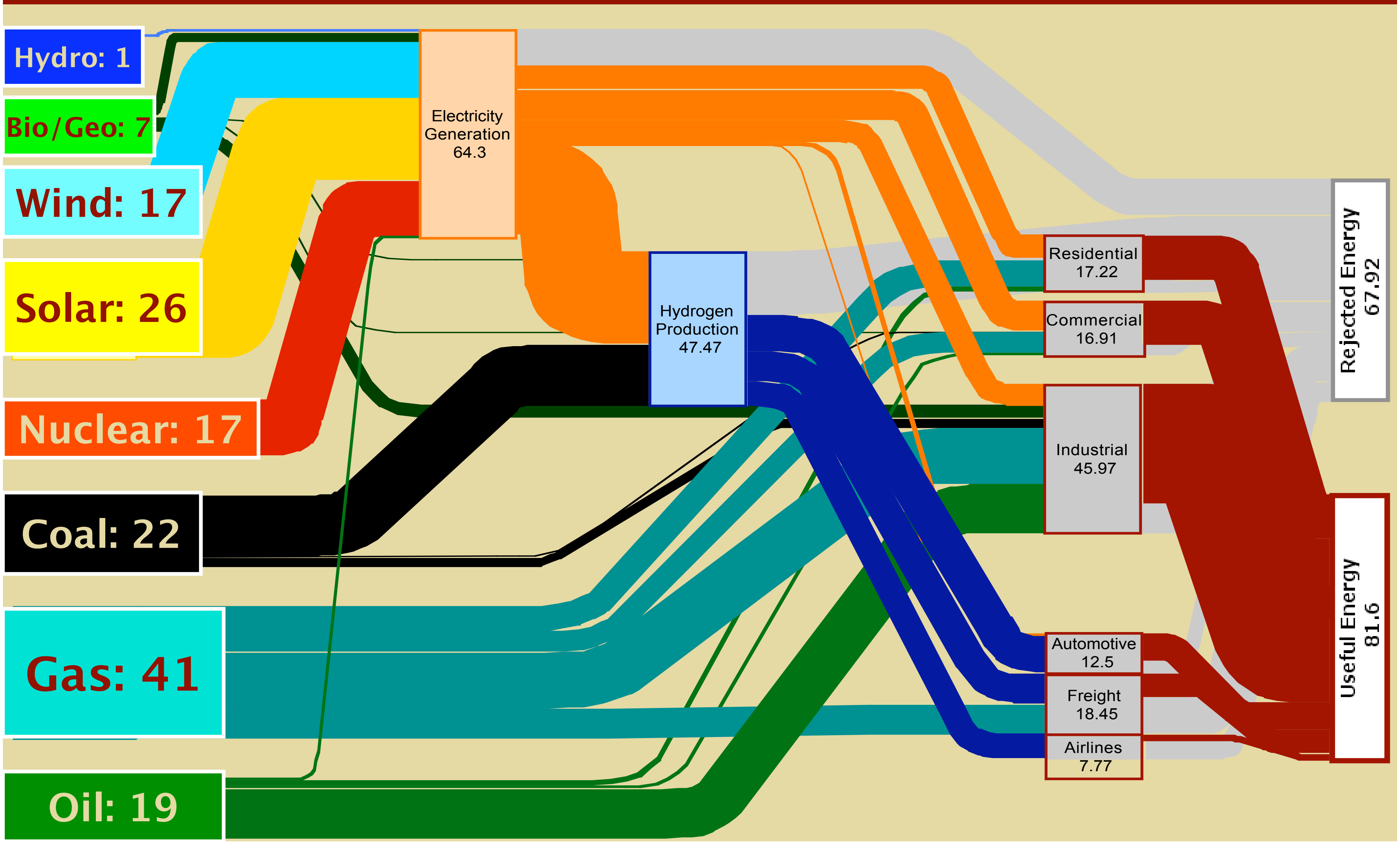
Compressed Air
Turbines
(low capital cost)

Fuel Cells
(hydrogen)

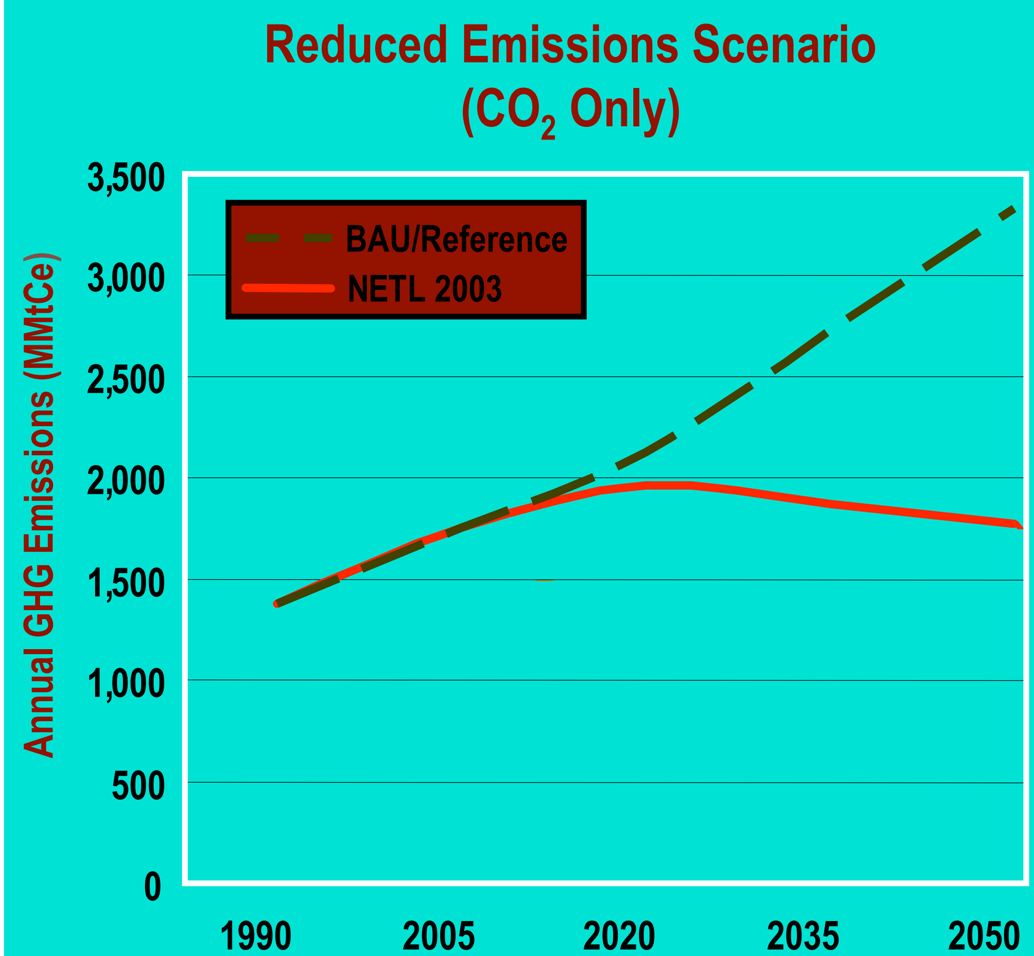
Massive Carbon-Free Power by 2050: An Aggressive Scenario (Berry & Lamont)

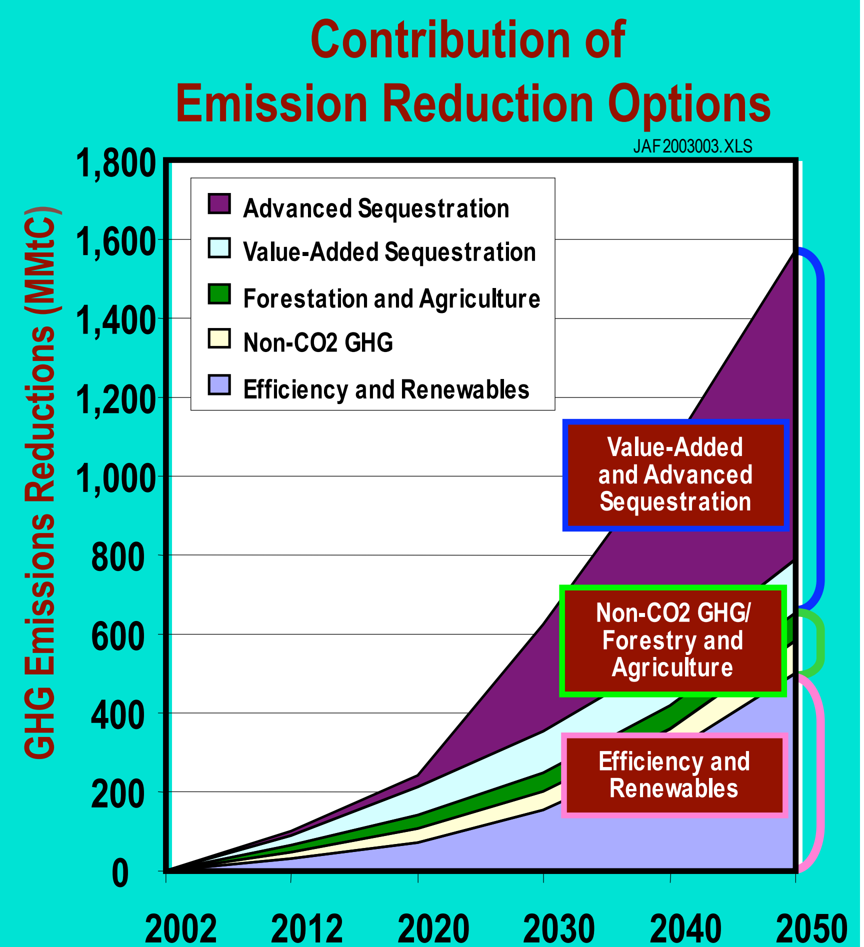
• U.S. Population	400 million people	(up 40%)
• Electricity Use	2 kWe/capita	(up 37%)
• Wind	300,000 5 MW Turbines (All the wind-power available from the Dakotas)	
• Solar PV	150 million 25 kW roofs (Every roof top in the United States)	
• Advanced Fission	300 1 GWe nuclear plants (50% efficient)	
• 100% H_2 Vehicles	"80 mpg" average for cars and SUV's 3 million H_2 trucks, 5000 LH_2 airliners	

Massive Carbon-Free U.S. 2050 Scenario (Berry & Lamont)
(~150 EJ/yr ~ 4.8 TW)
reduces carbon emissions to 1995 Levels (~1.4 GtC/yr)

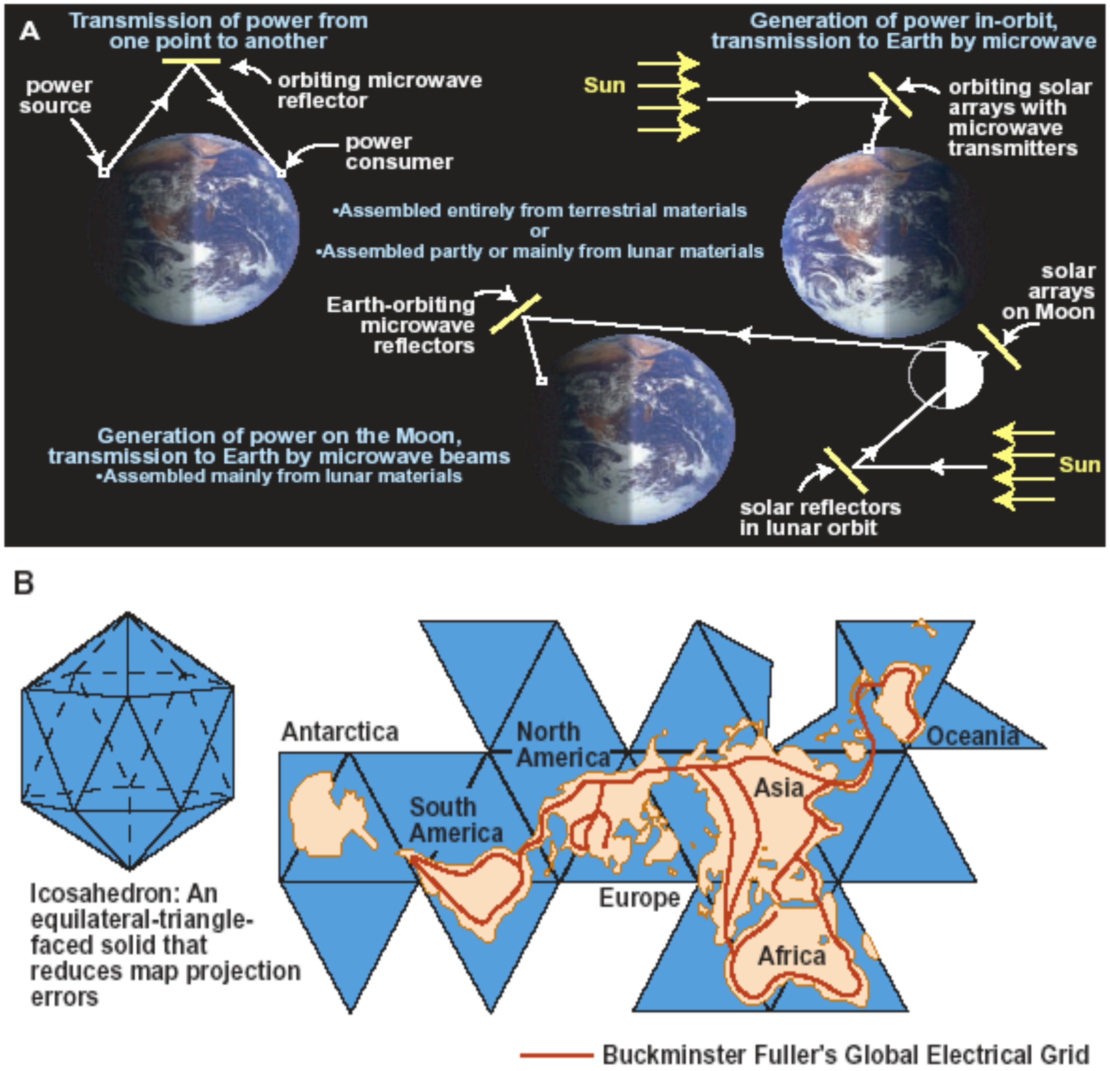


Carbon Sequestration-Dominated Path to 2050 for Controlling CO_2 Emissions (after Kuuskraa & Dipietro for NETL)





Source: NRDC, May 2003



A. Capturing Solar Energy in space (Peter Glaser et al., 1970s)

B. Global Superconducting Transmission Grid (Buckminster Fuller, 1970s)

Visionary Technology Systems that could Enable a Global Economy Powered by Renewable Energy.

World Energy Scheme for 30-60 TW in 2050: The Distributed Store-Gen Grid

(Rick Smalley, Rice University)

- Energy transported as electrical energy over wire, rather than by transport of mass (coal, oil, gas)
- Vast electrical power grid on continental scale interconnecting ~ 200 million asynchronous. “local” storage and generation sites, entire system continually innovated by free enterprise
- “Local” = house, block, community, business, town, …
- Local storage = batteries, flywheels, hydrogen, etc.
- Local generation = reverse of local storage + local solar and geo
- Local “buy low, sell high” to electrical power grid
- Local optimization of days of storage capacity & quality of local power
- Electrical grid does not need to be very reliable
- Mass Primary Power input to grid via HV DC transmission lines from existing plants plus remote (up to 2000 mile) sources on TW scale, including vast solar farms in deserts, wind, NIMBY nuclear, clean coal, stranded gas, wave, hydro, space-based solar (SPS and LPS)
- Hydrogen is transportation fuel

Third Stream Goal: Large-Scale Renewable & Sustainable Energy

- The US (& world) needs a "third stream" of sustained R&D emphasizing high-tech renewable energy (+efficiency) along side (1) coal-derived hydrogen and electricity with CO_2 sequestered in underground cavities ("FutureGen") and (2) advanced nukes including helium-cooled pebble bed reactors ("Generation III and IV nuclear reactors").

- IPCC Mitigation Panel finding that CO_2 stabilization energy technologies "already exist" is indefensible. Advanced technologies to expand the renewable energy contribution to major energy sources in the next 50 years are critical for long-term CO_2-emission-free power, sustainability & energy independence.

Renewables: A Third R & D Stream

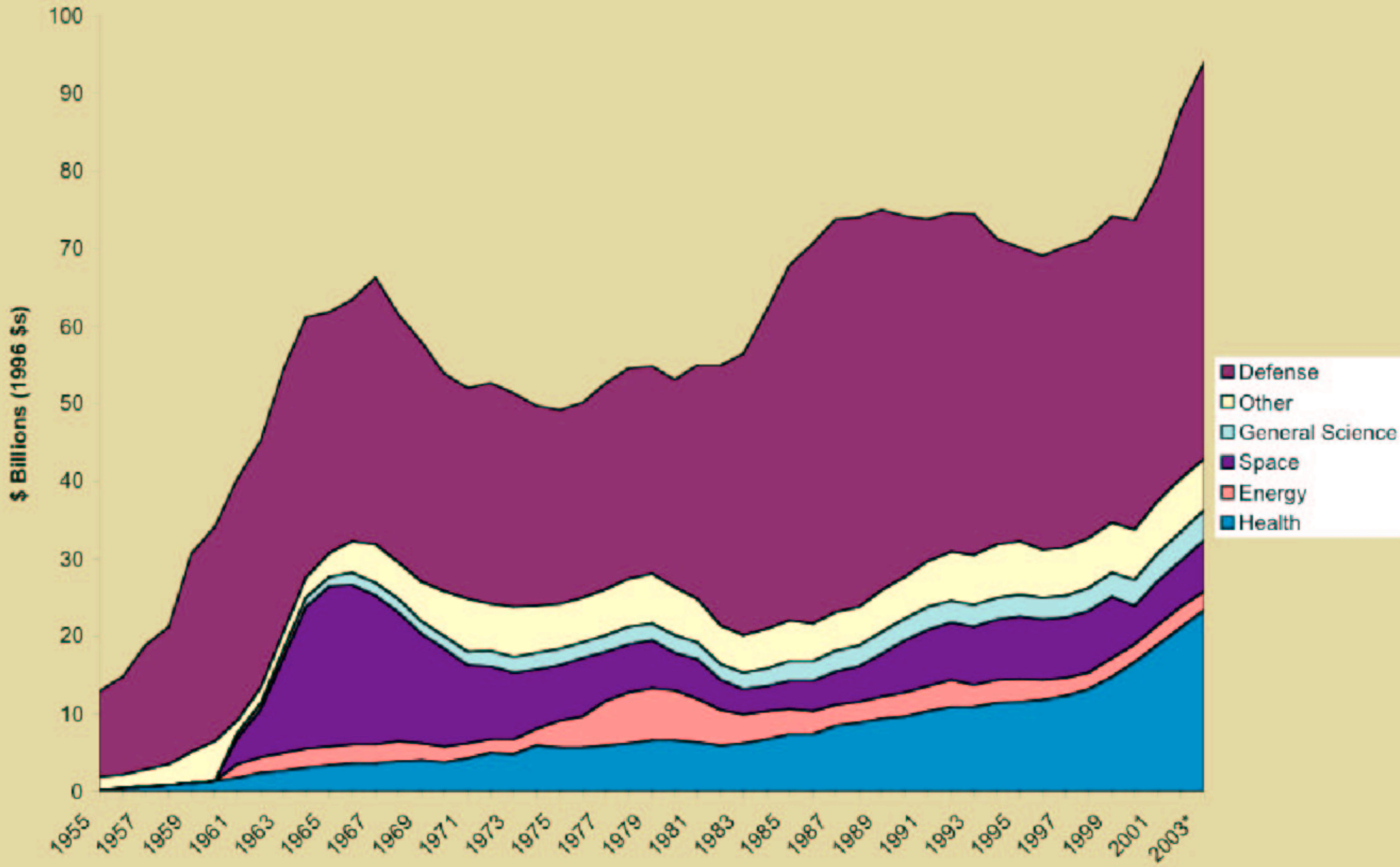
- **Systems analysis of massive-scale renewable electricity and hydrogen generation, emphasis on load matching. Long distance transmission versus distributed generation? Systems integration, physical limits & environmental impacts.**

- **Smart, low-loss grids: Computer modeling and high-tech hardware for rapid switching, grid interconnects, voltage changes, DC, low-resistance power lines, resilience to overload, intermittent sources and blackouts.**

- **Advanced Storage: Hydrogen, composite flywheels, superconductive inductive storage, compressed air, advanced pumped storage, integration of transportation and power generation sectors.**

- **Advanced Generating and Transmission Systems: Space solar power, superconducting grids, genetically engineered biofuels.**

History of Federal R & D (from Dan Kammen)



Source: National Science Foundation, Federal R&D Funding by Budget Function, Fiscal Years 2001-03.
* 2002 figures are preliminary, 2003 figures are proposed.

A broad spectrum Apollo-like program is needed. Nominal goal is generating 3-10 TW (thermal equiv.) emission-free from renewable sources by 2050. Typical projects should include:

- Demonstration of smart transmission grids & components
- Targeted programs on energy storage technologies
- “Leap-frog” technologies for developed & developing nations

Program design considerations:

- Program will target peak renewable energy contribution from innovative strategic technologies (nanotech, etc.)

  -- as opposed to risk-averse incrementalism
- DARPA-like program management: Bring promising & revolutionary technology into existence -- whatever it takes
- Open to all researchers in entrepreneurial, industry, university and government labs

SUMMARY AND CONCLUSIONS

NEAR TERM:

•R & D: Apollo-DARPA like “3rd Stream” for Renewables

•Smart Transmission Test Beds

•Expand regulatory mechanisms (RPS) to increase market share

•Avoid simple “beefing up of hub-and-spoke networks

MEDIUM TERM: Minimum of 10% renewable power

•Build Smart transmission system with dual power capability

•Renewable generation cost-competitive widely (not niche)

•Scale up Storage Capacity

BY 2050: Minimum 20% Renewable Power

•Lost-cost solar, wind, ocean, biomass power

•New breakthrough approaches not yet invented

What's Wrong with Pacala & Socolow?

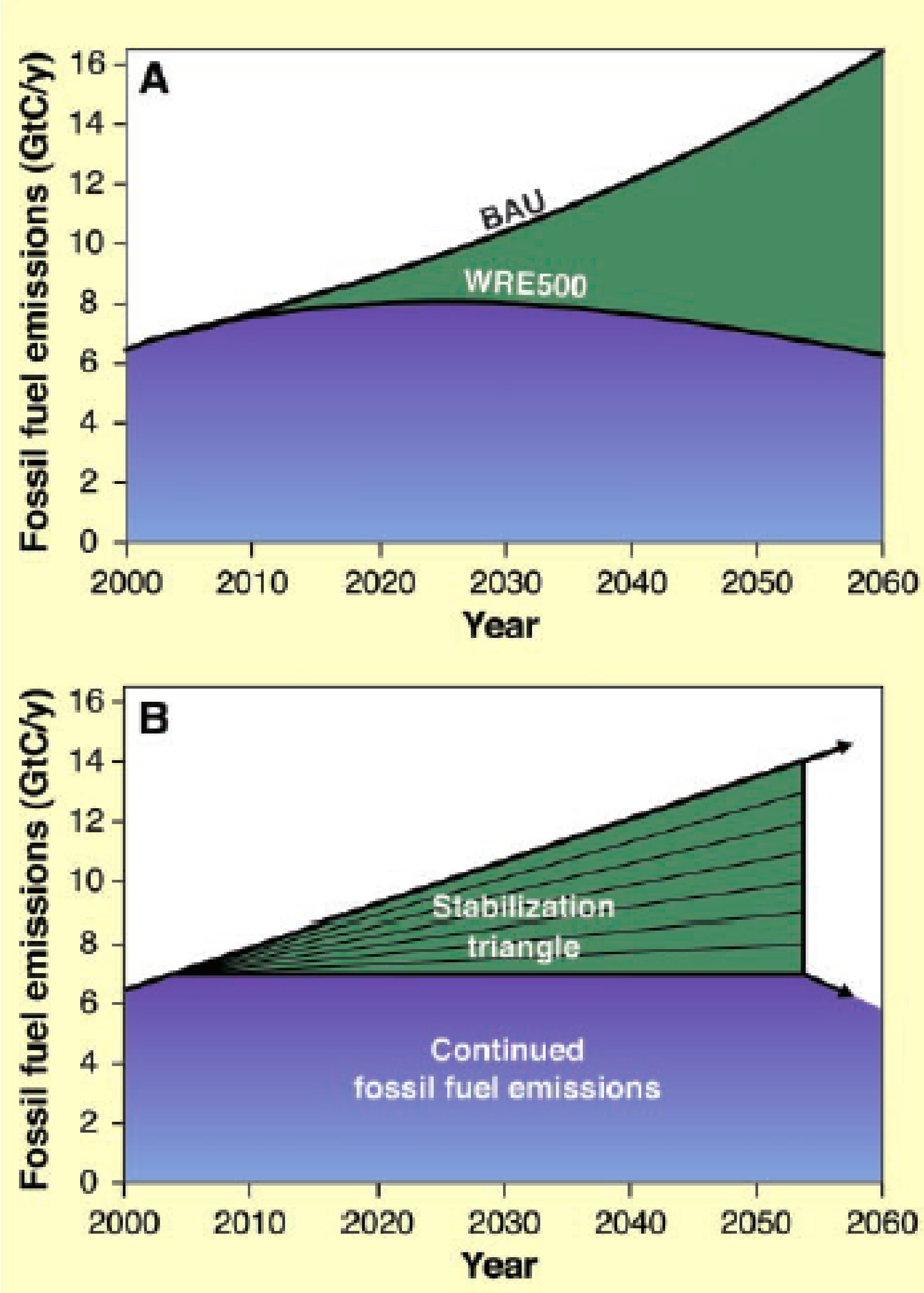
Their Abstract:

Humanity already possesses the fundamental scientific, technical, and industrial know-how to solve the carbon and climate problem for the next half-century. A portfolio of technologies now exists to meet the world's energy needs over the next 50 years and limit atmospheric CO_2 to a trajectory that avoids a doubling of the preindustrial concentration. Every element in this portfolio has passed beyond the laboratory bench and demonstration project; many are already implemented somewhere at full industrial scale. Although no element is a credible candidate for doing the entire job (or even half the job) by itself, the portfolio as a whole is large enough that not every element has to be used.

Sounds good. We should breath easier.
But there is trouble in Paradise

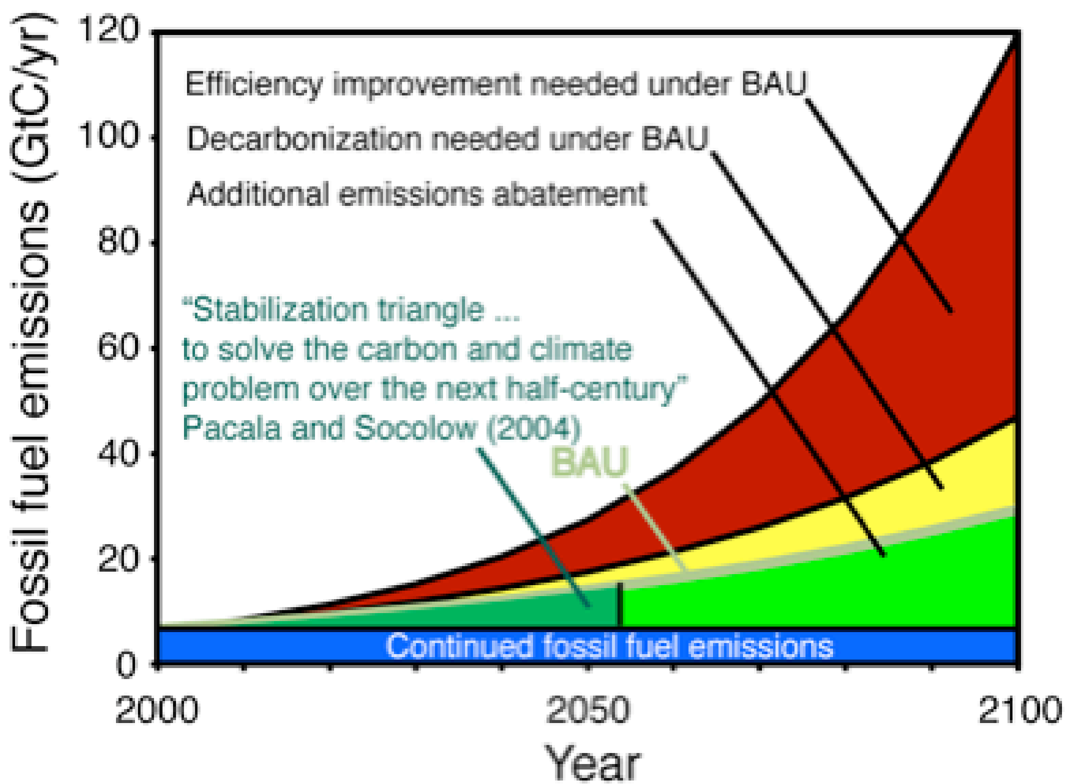
Table 1. Potential wedges: Strategies available to reduce the carbon emission rate in 2054 by 1 GtC/year or to reduce carbon emissions from 2004 to 2054 by 25 GtC.

Option	Effort by 2054 for one wedge, relative to 14 GtC/year BAU	Comments, issues
	Energy efficiency and conservation	
Economy-wide carbon-intensity reduction (emissions/$GDP)	Increase reduction by additional 0.15% per year (e.g., increase U.S. goal of 1.96% reduction per year to 2.11% per year)	Can be tuned by carbon policy
1. Efficient vehicles	Increase fuel economy for 2 billion cars from 30 to 60 mpg	Car size, power
2. Reduced use of vehicles	Decrease car travel for 2 billion 30-mpg cars from 10,000 to 5000 miles per year	Urban design, mass transit, telecommuting
3. Efficient buildings	Cut carbon emissions by one-fourth in buildings and appliances projected for 2054	Weak incentives
4. Efficient baseload coal plants	Produce twice today's coal power output at 60% instead of 40% efficiency (compared with 32% today)	Advanced high-temperature materials
	Fuel shift	
5. Gas baseload power for coal baseload power	Replace 1400 GW 50%-efficient coal plants with gas plants (four times the current production of gas-based power)	Competing demands for natural gas
	CO_2 Capture and Storage (CCS)	
6. Capture CO_2 at baseload power plant	Introduce CCS at 800 GW coal or 1600 GW natural gas (compared with 1060 GW coal in 1999)	Technology already in use for H_2 production
7. Capture CO_2 at H_2 plant	Introduce CCS at plants producing 250 MtH_2/year from coal or 500 MtH_2/year from natural gas (compared with 40 MtH_2/year today from all sources)	H_2 safety, infrastructure
8. Capture CO_2 at coal-to-synfuels plant	Introduce CCS at synfuels plants producing 30 million barrels a day from coal (200 times Sasol), if half of feedstock carbon is available for capture	Increased CO_2 emissions, if synfuels are produced without CCS
Geological storage	Create 3500 Sleipners	Durable storage, successful permitting
	Nuclear fission	
9. Nuclear power for coal power	Add 700 GW (twice the current capacity)	Nuclear proliferation, terrorism, waste
	Renewable electricity and fuels	
10. Wind power for coal power	Add 2 million 1-MW-peak windmills (50 times the current capacity) "occupying" 30 × 10^6 ha, on land or offshore	Multiple uses of land because windmills are widely spaced
11. PV power for coal power	Add 2000 GW-peak PV (700 times the current capacity) on 2 × 10^6 ha	PV production cost
12. Wind H_2 in fuel-cell car for gasoline in hybrid car	Add 4 million 1-MW-peak windmills (100 times the current capacity)	H_2 safety, infrastructure
13. Biomass fuel for fossil fuel	Add 100 times the current Brazil or U.S. ethanol production, with the use of 250 × 10^6 ha (one-sixth of world cropland)	Biodiversity, competing land use
	Forests and agricultural soils	
14. Reduced deforestation, plus reforestation, afforestation, and new plantations.	Decrease tropical deforestation to zero instead of 0.5 GtC/year, and establish 300 Mha of new tree plantations (twice the current rate)	Land demands of agriculture, benefits to biodiversity from reduced deforestation
15. Conservation tillage	Apply to all cropland (10 times the current usage)	Reversibility, verification



PS show that ~7 GtC/yr avoided carbon emissions by 2054 (7 “wedges”) is enough to move from BAU to a CO2 trajectory stabilizing eventually at 500 ppm. They don’t say how many wedges are needed to achieve BAU.

THIS IS A FATAL MISTAKE: Getting to BAU requires more wedges (24) than PS tabulate (15), so no available technology is left to stabilize CO2; i.e., Their Hypothesis Fails!



Emissions Growth rate (percent)	GtC/yr in 2054 Starting from 7 GtC/yr in 2004	GtC/yr reductions in 2054 needed to keep emissions at 7 GtC/yr
3.0%	30.7	23.7
2.0%	18.8	11.8
1.5%	14.7	7.7

Kaya equation

$$\dot{C} = GDP \times \frac{E}{GDP} \times \frac{C}{E}$$

Carbon emissions = Gross domestic product X Energy intensity X Carbon to energy emission factor